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For: BEAM HOMOGENIZER, LASER	)
IRRADIATION APPARATUS, AND	)
METHOD FOR MANUFACTURING	)
SEMICONDUCTOR DEVICE	)

VERIFICATION OF TRANSLATION

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Sir:

I, Yoshimi ANDOU, C/O Semiconductor Energy Laboratory Co., Ltd. 398, Hase, Atsugi-shi, Kanagawa-ken 243-0036 Japan, a translator, herewith declare:

that I am well acquainted with both the Japanese and English Languages;

that I am the translator of the attached translation of the Japanese Patent Application No. 2003-342803 filed on October 1, 2003; and

that to the best of my knowledge and belief the following is a true and correct translation of the Japanese Patent Application No. 2003-342803 filed on October 1, 2003.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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[Name of Document] Scope of Claims

[Claim 1]

A beam homogenizer for a beam spot to be a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface, comprising:

an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a major axis.

[Claim 2]

A beam homogenizer for forming a beam spot into a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface, comprising:

an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a major axis; and

one or plural cylindrical lenses for expanding and projecting a plane having homogenous energy distribution formed by the optical waveguide in the direction of the major axis of the rectangular beam spot to the irradiated surface.

[Claim 3]

A beam homogenizer for forming a beam spot into a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface, comprising:

means for homogenizing energy distribution in a direction of a minor axis of the rectangular beam spot on the irradiation surface; and

an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a major axis,

wherein the means comprises at least a cylindrical lens array.

[Claim 4]

A beam homogenizer for forming a beam spot into a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface, comprising:

an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a major axis; and

an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a minor axis.

[Claim 5]

A beam homogenizer according to any one of claims 1 to 4, wherein the optical waveguide comprises a pair of reflection planes provided oppositely.

[Claim 6]

A beam homogenizer according to any one of claims 1 to 5 according to any one of claims 1 to 4, wherein the optical waveguide is a light pipe.

[Claim 7]

A beam homogenizer according to any one of claims 1 to 6, wherein the aspect ratio is 100 or more.

[Claim 8]

A laser irradiation apparatus for a beam spot to be a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface, comprising:

a laser oscillator; and

a beam homogenizer,

wherein the beam homogenizer comprises an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a major axis.

[Claim 9]

A laser irradiation apparatus for a beam spot to be a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface, comprising:

a laser oscillator; and

a beam homogenizer,

wherein the beam homogenizer comprises an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a major axis, and means for homogenizing energy distribution in a direction of a minor axis of the rectangular beam spot, and

wherein the means comprises at least a cylindrical lens array.

[Claim 10]

A laser irradiation apparatus for a beam spot to be a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface, comprising:

a laser oscillator; and

a beam homogenizer,

wherein the beam homogenizer comprises an optical waveguide for homogenizing energy distribution of the rectangular beam spot in a direction of a major axis, and an optical waveguide for homogenizing energy distribution of the rectangular

beam spot in a direction of a minor axis.

[Claim 11]

A laser irradiation apparatus according to any one of claims 8 to 10, wherein the optical waveguide comprises a pair of reflection planes provided oppositely.

[Claim 12]

A laser irradiation apparatus according to any one of claims 8 to 11, wherein the optical waveguide is a light pipe.

[Claim 13]

A laser irradiation apparatus according to any one of claims 8 to 12, wherein the laser oscillator is any of an excimer laser, a YAG laser, and a glass laser.

[Claim 14]

A laser irradiation apparatus according to any one of claims 8 to 12, wherein the laser oscillator is any of a YVO_4 laser, a YLF laser, and an Ar laser.

[Claim 15]

A laser irradiation apparatus according to any one of claims 8 to 14, wherein the aspect ratio is 100 or more.

[Claim 16]

A laser irradiation apparatus according to any one of claims 8 to 15, wherein the laser irradiation apparatus comprises a moving stage for moving an irradiation object including the irradiation surface relative to the beam spot.

[Claim 17]

A laser irradiation apparatus according to claim 16, wherein the laser irradiation apparatus comprises a transferring apparatus for transferring an irradiation object including the irradiation surface to the moving stage.

[Claim 18]

A method for manufacturing a semiconductor device, comprising the steps of:

forming a non-single crystal semiconductor film over a substrate; and

performing a laser annealing to the non-single crystal semiconductor film while shaping a laser beam generated by a laser oscillator into a rectangular beam spot having an aspect ratio of 10 or more on an irradiation surface and having homogeneous energy distribution through a cylindrical lens array and an optical waveguide and while moving a position of the beam spot relative to the non-single crystal semiconductor film,

wherein the cylindrical lens array acts upon the rectangular beam spot in a direction of a minor axis, and

wherein the optical waveguide acts upon the rectangular beam spot in a direction of a major axis.

[Claim 19]

A method for manufacturing a semiconductor device, comprising the steps of:

forming a non-single crystal semiconductor film over a substrate; and

performing a laser annealing to the non-single crystal semiconductor film while shaping a laser beam generated by a laser oscillator into a rectangular beam spot having an aspect ratio of 10 or more on the irradiation and having homogenous energy distribution surface through a plurality of optical waveguides and while moving a position of the beam spot relative to the non-single crystal semiconductor film,

wherein at least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of a major axis, and

wherein at least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of a minor axis.

[Claim 20]

A method for manufacturing a semiconductor device according to claim 18 or 19, wherein the optical waveguide comprises a pair of reflection planes provided oppositely.

[Claim 21]

A method for manufacturing a semiconductor device according to any one of claims 18 to 20, wherein the optical waveguide is a light pipe.

[Claim 22]

A method for manufacturing a semiconductor device according to any one of claims 18 to 21, wherein the laser oscillator is any of an excimer laser, a YAG laser, and a glass laser.

[Claim 23]

A method for manufacturing a semiconductor device according to any one of claims 18 to 21, wherein the laser oscillator is any of a YVO_4 laser, a YLF laser, and an Ar laser.

[Claim 24]

A method for manufacturing a semiconductor device according to any one of claims 18 to 23, wherein the aspect ratio is 100 or more.

[Name of Document] Specification

[Title of the Invention] BEAM HOMOGENIZER, LASER IRRADIATION APPARATUS, AND METHOD FOR MANUFACTURING SEMICONDUCTOR DEVICE

[Technical Field]

[0001]

The present invention relates to a beam homogenizer for homogenizing a beam spot on an irradiation surface in a certain region. In addition, the present invention relates to a laser irradiation apparatus for irradiating the irradiation surface with the beam spot. Furthermore, the present invention also relates to a method for manufacturing a semiconductor device using a crystalline semiconductor film formed with the laser irradiation apparatus.

[Background Art]

[0002]

In recent years, there has been a technique widely studied for crystallizing and enhancing a crystallinity of an amorphous semiconductor film or a crystalline semiconductor film (a semiconductor film having a crystallinity such as poly-crystal or micro-crystal, which is not single-crystal), that is to say, a semiconductor film which is not single-crystal (referred to as a non-single crystalline semiconductor film) formed over an insulating substrate such as a glass substrate with laser annealing performed thereto. A silicon film is often used as the semiconductor film.

[0003]

In comparison with a quartz substrate that has been often used conventionally, a glass substrate has advantages that it is inexpensive and superior in workability, and that it can be processed easily into a large sized substrate. This is the reason why the above study has been extensively conducted. A laser is preferably used for crystallization because the glass substrate has a low melting point. A laser can give high energy only to the non-single crystal semiconductor film without changing the temperature of the substrate too much.

[0004]

A crystalline silicon film formed with the laser annealing performed has a high mobility. Therefore, a thin film transistor (TFT) formed with this crystalline silicon

film is used extensively. For example, the TFT is extensively used for a monolithic liquid crystal electro-optical device and the like, in which a TFT for a pixel and a TFT for a driver circuit are formed over one glass substrate. The crystalline silicon film is referred to as a poly-crystalline silicon film or a poly-crystalline semiconductor film because the crystalline silicon film is formed of a number of crystal grains.

[0005]

In addition, it is possible to shape by an optical system a laser beam oscillated from a pulsed laser oscillator having high output such as an excimer laser into a square spot with several cm on a side or into a linear spot with 10 cm or more in length on an irradiation surface (for example, Patent Document 1). Then such an irradiation position of the beam spot is scanned relative to the irradiation surface to perform the laser annealing. Since such a method can enhance productivity and is superior industrially, it is preferably employed.

[0006]

In particular, when the linear beam spot is employed, unlike in the case that a punctate beam spot requiring to be scanned from front to back and from side to side is employed, the linear beam spot can provide high productivity since an entire irradiation surface can be irradiated with the laser beam by scanning the linear beam spot only in a direction perpendicular to the direction of its major axis. It is noted that the linear beam spot here means a rectangular beam spot having a high aspect ratio. The beam spot is scanned in the direction perpendicular to the direction of the major axis of the linear beam spot because it is the most effective scanning direction. Because of such high productivity, at present, the laser annealing is mainly employing the linear beam spot obtained by shaping a pulsed excimer laser beam spot through an appropriate optical system.

[0007]

Fig. 6 shows an example of the optical system for forming a cross-sectional shape of a beam spot into linear on the irradiation surface. The optical system shown in Fig. 6 is an extremely general optical system. The optical system not only converts the cross-sectional shape of the beam spot into linear but also homogenizes the energy of the beam spot on the irradiation surface simultaneously. Generally, the optical system for homogenizing the energy of the beam is referred to as a beam homogenizer.

The optical system shown in Fig. 6 is also a beam homogenizer.

[0008]

First, a side view of Fig. 6(a) is explained. A laser beam oscillated from a laser oscillator 1201 divides the laser beam spot in one direction through cylindrical lens arrays 1202a and 1202b. The direction is referred to as a longitudinal direction. When a mirror is inserted in the optical system, a beam spot in the longitudinal direction is bent to the direction bent by the mirror. The laser beam is divided into four beams in this structure. These divided spots are combined into one spot with a cylindrical lens 1204 once. After the spots separated again are reflected on a mirror 1207, the beam spots are converged into one spot again through a doublet cylindrical lens 1208 on an irradiation surface 1209. A doublet cylindrical lens is a set of lenses consisting of two cylindrical lenses. Accordingly, the energy of the beam spot shaped into linear in the longitudinal direction is homogenized and the length thereof in the longitudinal direction is determined.

[0009]

Next, a plane view of Fig. 6(b) is explained. A laser beam oscillated from the laser oscillator 1201 divides the laser beam spot in a direction perpendicular to the longitudinal direction through a cylindrical lens array 1203. The direction perpendicular to the longitudinal direction is referred to as a lateral direction. When a mirror is inserted in the optical system, a beam spot in the lateral direction is bent to the direction bent by the mirror. The laser beam is divided into seven beam spots in this structure. After that, the beam spots divided into seven beam spots are combined into one beam spot on the irradiation surface 1209 through a cylindrical lens 1205. A dotted line, which is shown after the mirror 1207, shows a correct optical path and correct positions of the lens and the irradiation surface in the case of not disposing the mirror 1207. Accordingly, the energy distribution of the beam spot shaped into linear in the lateral direction is homogenized and the length thereof in the horizontal direction is determined.

[0010]

As described above, the cylindrical lens arrays 1202a, 1202b, and 1203 serve as the lenses for dividing the spot of the laser beam. The number of the divided beam spots determines the homogeneity of the energy distribution of the obtained linear beam

spot.

[0011]

Each of the lenses is made of synthetic quartz in order to correspond with the XeCl excimer laser. In addition, the lenses have coated surfaces thereon so as to transmit the excimer laser very well. This makes transmittance of the excimer laser become 99% or more per one lens.

[0012]

Irradiation is performed as the linear beam spots shaped through the above structure are overlapped in such a way that the linear beam spots are displaced gradually in the direction of the line width of the beam spot. With such irradiation performance, the laser annealing can be conducted to the whole surface of the non-single crystal silicon film, for example, so as to crystallize it or to enhance its crystallinity.

[0013]

Next, a typical method for manufacturing a semiconductor film, which is an object to be irradiated with the laser beam, is shown. Initially, a glass substrate having a thickness of 0.7 mm and a length of 5 inch on a side is used. A SiO_2 film (a silicon oxide film) is formed over the substrate in about 200 nm thick with a plasma-CVD apparatus, and an amorphous silicon film (hereinafter referred to as an a-Si film) is formed in about 50 nm thick over a surface of the SiO_2 film. When the substrate is exposed to the atmosphere of nitrogen at a temperature of 500°C for one hour, hydrogen concentration in the film is decreased. Accordingly, the resistivity of the film is considerably increased against the laser beam.

[0014]

A XeCl excimer laser (wavelength 308 nm, pulse width 30 ns) is used as the laser oscillator. A spot size of the laser beam is 15 mm × 35 mm at an exit of the laser beam (both are width at half maximum). The exit of laser beam is defined as a plane perpendicular to the traveling direction of the laser beam just after the laser beam is emitted from the laser oscillator.

[0015]

The laser beam emitted from the excimer laser generally has a rectangular shape, and when it is expressed with an aspect ratio, the rectangular beam has an aspect ratio ranging from approximately 1 to 5. The intensity of the laser beam spot indicates

Gaussian distribution, in which the intensity of the laser beam becomes higher toward the center thereof. The spot size of the laser beam is converted into a spot shape having homogeneous energy distribution, for example, a linear beam spot having a size of 300 mm × 0.4 mm through the optical system shown in Fig. 6.

[0016]

When the semiconductor film is irradiated with the laser beam, about 1/10 of the minor width (width at half maximum) of the linear beam spot is the most appropriate pitch for overlapping the laser beam spot. Accordingly, the homogeneity of the crystallinity in the semiconductor film can be improved. In the above example, since the width at half maximum is 0.4 mm, the laser beam irradiation is performed under the condition of the excimer laser in which the pulse frequency is set to 300 Hz, and the scanning speed is set to 10 mm/s. On this occasion, the energy density of the laser beam on the irradiation surface is set to 450 mJ/cm^2. The method described above is a very general method for crystallizing the semiconductor film with the linear beam spot.

[0017]

[Patent Document 1]

Japanese Patent Application Laid-Open No. H9-234579

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0018]

The above cylindrical lens array requires to be manufactured with high accuracy.

[0019]

The cylindrical lens array is a lens with cylindrical lenses arranged in a direction of each curvature. Here, the direction of the curvature is defined as a direction perpendicular to a generatrix of a cylindrical surface of the cylindrical lens. The cylindrical lens array always has a joint between the cylindrical lenses constituting the cylindrical lens array. Since the joint does not have a curved surface as the cylindrical lens, a light beam being incident on the joint is transmitted without being influenced by the cylindrical lens. The light beam reaching the irradiation surface without being influenced by the cylindrical lens may cause inhomogeneity of the energy

distribution of the rectangular beam spot on the irradiation surface.

[0020]

In addition, all the cylindrical lenses constituting the cylindrical lens array must be manufactured with the same accuracy. When the cylindrical lenses have different curvatures, the light beams divided by the cylindrical lens array are not overlapped in the same position on the irradiation surface even with a converging lens. In other words, the region where the energy is attenuated in the rectangular beam spot on the irradiation surface increases. This causes a lowering of the energy use efficiency.

[0021]

The cause of the inhomogeneity of the energy distribution of the beam spot on the irradiation surface lies in the structural problem and the manufacturing accuracy of the cylindrical lens array constituting the optical system. More specifically, one of the causes of the inhomogeneity is that not all of the light beams divided by the cylindrical lens array are overlapped in the same position.

[0022]

Furthermore, when the semiconductor film is irradiated and scanned with the rectangular beam spot having inhomogeneous energy distribution in the direction of its major axis on the irradiation surface, the crystallinity of the semiconductor film becomes inhomogeneous in a reflection of the inhomogeneous distribution. The inhomogeneity of the crystallinity is synchronized with the inhomogeneity of the characteristic of the semiconductor film such as the electric mobility. For example, the inhomogeneous crystallinity appears as a variation of an electric characteristic of the TFT formed using the semiconductor film, and displays light and shade pattern on a panel using the TFT.

[0023]

The present invention is made in view of the above problem. The present invention provides a beam homogenizer being able to form a rectangular beam spot having homogeneous energy distribution in the direction of its major axis on the irradiation surface without using an optical lens that is necessary to be manufactured with high accuracy. In addition, the present invention provides a laser irradiation apparatus being able to perform irradiation with a laser beam having a rectangular beam spot with homogeneous energy distribution in the direction of its major axis.

Furthermore, the present invention provides a method for manufacturing a semiconductor device, being able to enhance the homogeneity of the crystallinity in a substrate surface and to manufacture a TFT with high operating characteristic.

[Means for Solving the Problem]

[0024]

The present invention employs an optical waveguide as the optical system for homogenizing the energy distribution of the rectangular beam spot in the direction of its major axis on the irradiation surface in the optical system for forming the above rectangular beam spot. The optical waveguide is a circuit being able to keep radiation light in a certain region and to transmit the radiation light in such a way that the energy flow thereof is guided in parallel with an axis of the channel.

[0025]

A beam homogenizer disclosed in this specification is a beam homogenizer for shaping a beam spot on an irradiation surface into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, which has a feature to include an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in the direction of its major axis.

[0026]

In the present invention, the reason why the optical waveguide is used in the beam homogenizer is explained as follows. When the light beams are incident on the optical waveguide, the light beams are reflected in the optical waveguide repeatedly and are led to the exit surface. In other words, the light beams being incident on the optical waveguide are overlapped as if the incident light beams are folded on the exit surface, which is the same position. Therefore, the energy distribution of the light beams is homogenized on the exit surface, on which the light beams are overlapped, since the light beams being incident on the optical waveguide are divided and obtain a similar effect to a case that the divided light beams are overlapped in the same position.

[0027]

Another aspect of the present invention is a beam homogenizer for shaping a beam spot on an irradiation surface into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more. The beam homogenizer has a feature to include an optical waveguide for homogenizing the energy distribution of the rectangular beam

spot in a direction of its major axis, and one or more cylindrical lenses for converging the light emitted from the optical waveguide in the direction of its major axis on the irradiation surface.

[0028]

Another aspect of the present invention is a beam homogenizer for shaping a beam spot on an irradiation surface into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more. The beam homogenizer has a feature to include a means for homogenizing the energy distribution of the rectangular beam spot in a direction of its minor axis on the irradiation surface, and an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis, wherein the means has at least a cylindrical lens array.

[0029]

Another aspect of the present invention is a beam homogenizer for shaping a beam spot on an irradiation surface into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more. The beam homogenizer has a feature to include an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis, and an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its minor axis.

[0030]

In the above aspect of the beam homogenizer in the present invention, the optical waveguide has a feature to include a pair of reflection planes provided oppositely.

[0031]

It is noted that a light pipe can be used as the optical waveguide. The light pipe is usually extended into a circular cone, a pyramidal shape, a column, a prism, or the like, which transmits light from one end to the other end by reflection. It is noted that the light may be transmitted by mirror reflection, and a pair of reflection planes provided oppositely may be employed, for example.

[0032]

A laser irradiation apparatus disclosed in this specification is a laser irradiation apparatus in which a rectangular beam spot has an aspect ratio of 10 or more, preferably 100 or more, on an irradiation surface. The laser irradiation apparatus has a feature to

include a laser oscillator and a beam homogenizer, wherein the beam homogenizer has an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis.

[0033]

Another aspect of the present invention is a laser irradiation apparatus in which a beam spot is a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more, on an irradiation surface. The laser irradiation apparatus has a feature to include a laser oscillator and a beam homogenizer, wherein the beam homogenizer has an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its major axis and an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in a direction of its minor axis.

[0034]

In the above aspect of the laser irradiation apparatus in the present invention, the optical waveguide has a pair of reflection planes provided oppositely.

[0035]

It is noted that a light pipe can be used as the optical waveguide.

[0036]

In the above aspect of the laser irradiation apparatus in the present invention, the laser oscillator has a feature to be any of an excimer laser, a YAG laser, a glass laser, a YVO_4 laser, a YLF laser, and an Ar laser.

[0037]

In the above aspect of the laser irradiation apparatus in the present invention, the laser irradiation apparatus has a feature to include a moving stage for moving an object to be irradiated with a beam spot relative to the beam spot and to further include a transferring apparatus for transferring the object to be irradiated to the stage.

[0038]

A method for manufacturing a semiconductor device disclosed in the present invention has a feature to include a step of forming a non-single crystal semiconductor film over a substrate, and a step of performing laser annealing to the non-single crystal semiconductor film assuming that the non-single crystal semiconductor film is an irradiation surface while shaping a laser beam generated by a laser oscillator into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more on

the irradiation surface and having homogeneous energy distribution through a cylindrical lens array and an optical waveguide and while moving a position of the beam spot relative to the non-single crystal semiconductor film. The cylindrical lens array acts upon the rectangular beam spot in a direction of its minor axis, and the optical waveguide acts upon the rectangular beam spot in a direction of its major axis.

[0039]

Another aspect of the present invention has a feature to include a step of forming a non-single crystal semiconductor film over a substrate, and a step of performing laser annealing to the non-single crystal semiconductor film assuming that the non-single crystal semiconductor film is an irradiation surface while shaping a laser beam generated by a laser oscillator into a rectangular beam spot having an aspect ratio of 10 or more, preferably 100 or more on the irradiation surface and having homogeneous energy distribution through a plurality of optical waveguides and while moving a position of the beam spot relative to the non-single crystal semiconductor film. At least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of its major axis, and at least one of the plurality of optical waveguides acts upon the rectangular beam spot in a direction of its minor axis.

[0040]

It is noted that a light pipe can be used as the optical waveguide.

[0041]

In the above aspect of the method for manufacturing a semiconductor device in the present invention, the laser oscillator has a feature to be any of an excimer laser, a YAG laser, a glass laser, a YVO_4 laser, a YLF laser, and an Ar laser.

[Effect of the Invention]

[0042]

The laser irradiation apparatus disclosed in the present invention has a feature to include a beam homogenizer equipped with an optical waveguide. The optical waveguide has a pair of reflection planes provided oppositely and can homogenize the energy distribution of the rectangular beam spot in a direction of its major axis on the irradiation surface.

[0043]

When the beam homogenizer for forming a rectangular beam spot with the

optical waveguide disclosed in the present invention is used, it becomes possible to form the rectangular beam spot having the homogeneous energy distribution in a direction of its major axis on the irradiation surface without using the optical lens that requires to be manufactured with high accuracy. In addition, the optical waveguide is more preferable since it acts upon the rectangular beam spot in a direction of its minor axis and can also homogenize the energy distribution in the direction thereof on the irradiation surface. When the rectangular beam spot emitted from the laser irradiation apparatus with the use of this beam homogenizer is scanned on the semiconductor film in a direction of its minor axis, the inhomogeneity of the crystallinity due to the inhomogeneity of the energy distribution of the beam spot can be suppressed, and the homogeneity of the crystallinity in the substrate surface can be enhanced. In addition, when the present invention is applied to a mass-production line of low-temperature polysilicon TFTs, it is possible to manufacture TFTs with a uniform characteristic having high operating characteristics. Furthermore, when the low-temperature polysilicon is applied to a liquid crystal display device or a light-emitting device with the use of a light-emitting element as represented by an organic EL element, it becomes possible to manufacture a display device having very little display unevenness.

[Best Mode for Carrying out the Invention]

[0044]

First, a method for homogenizing the energy distribution of the beam spot with the use of the optical waveguide is explained in reference to Fig. 1. Initially, a plane view of Fig. 1(a) is explained. An optical waveguide 102 having a pair of reflection planes 102a and 102b provided oppositely, and an irradiation surface 103 are prepared, and light beams are made incident from the left side on the paper. When there is the optical waveguide 102, the light beams are drawn with continuous lines 101a. When there is not the optical waveguide 102, the light beams are drawn with dotted lines 101b. When there is not the optical waveguide 102, the light beams being incident from the left side on the paper reach regions of irradiation surfaces 103a, 103b and 103c as indicated with dotted lines 101b.

[0045]

On the other hand, when there is the optical waveguide 102, as indicated with the light beams 101a, the light beams are reflected by the reflection planes of the optical

waveguide 102 and all the light beams reach the region of the irradiation surface 103b. In other words, all the light beams that reach the regions of the irradiation surfaces 103a and 103c in the case that the optical waveguide 102 is not provided, reach the region of the irradiation surface 103b in the case that the optical waveguide 102 is provided. Thus, when the light beams are made incident on the optical waveguide 102, the light beams are reflected repeatedly in the optical waveguide and are led to the exit. That is to say, the light beams are overlapped as if the incident light beams are folded on the irradiation surface 103b, which is the same position. In this example, the length of the total light divergence 103a, 103b, and 103c on the irradiation surface 103 when there is not the optical waveguide is defined as A, and the length of the light divergence 103b on the irradiation surface 103 when there is the optical waveguide is defined as B. Then, A/B corresponds to the number of laser beams divided by the homogenizer described in the conventional art. Thus, when the incident light beam is divided and all the divided light beams are overlapped in the same position, the energy distribution of a light beam is homogenized in the overlapped position.

[0046]

Usually, the more the homogenizer divides the light beam, the more homogeneous the energy distribution becomes in the position where the divided light beams are overlapped. The number of the light beams divided in the optical waveguide 102 can be increased when the light beams are reflected more times in the optical waveguide 102. In other words, the length of a pair of reflection planes of the optical waveguide in the direction from which the light beams are incident is preferably made longer. In addition, the number of divided light beams can be increased by narrowing the space between the reflection planes provided oppositely, or by enhancing NA (numerical aperture) of the light beam being incident.

[0047]

The optical system for forming a rectangular beam spot including the beam homogenizer disclosed in the present invention is explained with reference to Fig. 2. In a plane view of Fig. 2(a), the vertical direction on the paper is the direction of the minor axis of the rectangular beam spot. Hereinafter, a light pipe can be used as the optical waveguide.

[0048]

First, the plane view of Fig. 2(a) is explained. A laser beam emitted from a laser oscillator 201 is propagated to the direction indicated by an arrow in Fig. 2, and then the laser beam is incident on a cylindrical lens 202. The laser beam is focused through the cylindrical lens 202 in the direction of the major axis of the rectangular beam spot, and then is incident on an optical waveguide 203 having a pair of reflection planes 203a and 203b provided oppositely. The laser beam being incident on the optical waveguide 203 is reflected repeatedly in the optical waveguide 203 and is led to the exit. A plane having the homogeneous energy distribution in the direction of the major axis of the rectangular beam spot is formed at the exit of the optical waveguide 203. Concerning the shape of the optical waveguide 203, for example, the optical waveguide 203 may have a length of 300 mm in the direction from which the light beam is incident, and a distance of 2 mm between the reflection planes.

[0049]

The longer the length of the optical waveguide 203 in the direction from which the light beam is incident is, or the shorter the focal length of the cylindrical lens 202 is, the more homogeneous the energy distribution becomes. However, the actual system must be manufactured in consideration of the size of the optical system, and thereby the length of the optical waveguide and the focal length of the cylindrical lens must be practical in accordance with the size of the system.

[0050]

A plane having the homogeneous energy distribution in the direction of the major axis of the rectangular beam spot formed at the exit of the optical waveguide 203 is projected to an irradiation surface 208, through a cylindrical lens 204. In other words, the plane having the homogeneous energy distribution and the irradiation surface 208 are conjugated with respect to the cylindrical lens 204. This homogenizes the energy distribution of the rectangular beam spot in the direction of its major axis and determines the length thereof in the direction of its major axis.

[0051]

The present invention having the optical waveguide 203 can remedy the structural problem and the problem of the manufacturing accuracy, of the cylindrical lens array, and the problem of the manufacturing accuracy of the cylindrical lens for converging the divided light beams, which cause the inhomogeneity of the energy

distribution of the rectangular beam spot on the irradiation surface in the conventional optical system.

[0052]

Next, a side view of Fig. 2(b) is explained. The laser beam emitted from the laser oscillator 201 is divided through cylindrical lens arrays 205a and 205b in the direction of the minor axis of the rectangular beam spot. The laser beams divided by the cylindrical lens arrays 205a and 205b are overlapped on the same plane by a cylindrical lens 206 to homogenize the energy distribution of the rectangular beam spot in the direction of its minor axis.

[0053]

A plane having the homogeneous energy distribution in the direction of the minor axis of the rectangular beam spot formed by the cylindrical lens 206 is projected to the irradiation surface 208 through a doublet cylindrical lens consisting of cylindrical lenses 207a and 207b. This homogenizes the energy distribution of the rectangular beam spot in the direction of its minor axis and determines the length thereof in the direction of its minor axis on the irradiation surface 208. The doublet cylindrical lens does not need to be employed, but when the doublet cylindrical lens is employed, spatial margin can be given because a distance can be secured between the optical system and the irradiation surface. It is noted that when the homogeneity of the beam spot on the irradiation surface is not required too much, or when F-number of the doublet cylindrical lens is extremely high, a singlet cylindrical lens may be employed.

[0054]

With the optical system formed of the structure explained above, it is possible to form the rectangular beam spot having the homogeneous energy distribution in the directions of its major axis and its minor axis on the irradiation surface.

[0055]

The laser oscillator to be combined with the optical system for forming the rectangular beam spot including the beam homogenizer disclosed in the present invention preferably has high output and the wavelength range that is easy to be sufficiently absorbed in the semiconductor film. When a silicon film is employed as the semiconductor film, the wavelength of the laser beam emitted from the laser oscillator to be used is preferably not longer than 600 nm in consideration of the

absorption ratio. For example, there are an excimer laser, a YAG laser (harmonic), and a glass laser (harmonic) given as the laser oscillator emitting such a laser beam.

[0056]

In addition, although high output has not been obtained yet in the conventional technology, there are, for example, a YVO_4 laser (harmonic), a YLF laser (harmonic), and an Ar laser given as the laser oscillator emitting a laser beam having an appropriate wavelength for crystallizing the silicon film.

[0057]

Hereinafter, a method for manufacturing a semiconductor device of the present invention by using the beam homogenizer and the laser irradiation apparatus of the present invention is explained. First, a substrate having a size of 600 mm × 720 mm × 0.7 mm is prepared as the substrate, for example. A no-alkali glass substrate having enough resistance against the heat up to 600°C typically such as an aluminoborosilicate glass, a bariumborosilicate glass or an aluminosilicate glass can be used as this substrate. A silicon oxide film is formed in 200 nm thick over the glass substrate as a base film. Moreover, an amorphous silicon film is formed in 55 nm thick over the base film. These films are both formed with sputtering. They may be formed with plasma-CVD alternatively.

[0058]

The above mentioned substrate with the films formed thereon is put in an atmosphere of nitrogen at a temperature ranging from 450 to 500°C for 1 to 3 hours. This process is to reduce hydrogen concentration in the amorphous silicon film. This process is performed since the film cannot resist against the laser energy when the amorphous silicon film contains too much hydrogen. The hydrogen concentration in the amorphous silicon film is appropriate to be on the order of 10^{20} /cm^3. Here, 10^{20} /cm^3 means that 10^{20} hydrogen atoms exist in 1 cm^3.

[0059]

For example, in this embodiment mode of the present invention, a XeCl excimer laser is used as the laser oscillator. In this embodiment, the XeCl excimer laser (wavelength 308 nm, pulse width 30 ns) STEEL 1000 manufactured by Lambda Physik, Inc. is employed. The excimer laser is a pulsed laser. The excimer laser has a maximum energy of 1000 mJ per a pulse, an oscillation wavelength of 308 nm, and a

maximum frequency of 300 Hz. When the energy of the pulsed laser fluctuates within ±10%, preferably within ±5%, in every pulse during the laser treatment to one substrate, homogeneous crystallization can be performed.

[0060]

The energy fluctuation of the laser described above is defined as follows. That is to say, the average value of the laser energy in the period of the irradiation of one substrate is assumed to be standard. Then, the energy fluctuation of the laser is defined as the value expressing, in percentage, the difference between the average value and the minimum value in the period of the irradiation or the difference between the average value and the maximum value in the period of the irradiation.

[0061]

In addition, the XeCl excimer laser (oscillation wavelength 308 nm, pulse width 170 ns) VEL 1520 manufactured by Sopra, Inc. may be also employed as the laser oscillator for example. The excimer laser has a maximum energy of 15 J per a pulse and a frequency of 20 Hz. In the case of using the above excimer laser, since the energy fluctuation can be suppressed within ±2.5% in every pulse during the laser treatment to one substrate, more homogeneous crystallization can be performed. In addition, when the optical system including the optical waveguide of the present invention is employed, the position of the beam spot on the irradiation surface is not affected by the fluctuation of the laser beam at all. Therefore, when the optical waveguide is used in combination with the laser having extremely stable output such as VEL 1520, it is possible to perform very uniform laser annealing.

[0062]

Irradiation with the laser beam is performed, for example, while scanning the stage with the irradiation surface 208 shown in Fig. 2 mounted thereon in the direction of the minor axis of the rectangular beam spot. On this occasion, a practitioner may decide the energy density and the scanning speed of the beam spot on the irradiation surface appropriately. The energy density may be appropriate to be in the range of 200 mJ/cm^2 to 1000 mJ/cm^2. It is feasible to perform laser annealing homogeneously when the scanning speed is selected appropriately in the range where the widths of the rectangular beam spots in the direction of their minor axes are overlapped one another by about 90% or more. The optimum scanning speed depends upon the frequency of

the laser oscillator, and it may be regarded to be proportional to the frequency thereof.

[0063]

In this way, the laser annealing process is completed. When the above process is performed repeatedly, many substrates can be processed. In addition, when a substrate holder being able to store a plurality of substrates and a transferring apparatus for transferring the plurality of substrates automatically between the substrate holder and the stage are prepared, substrates can be processed more effectively. For example, an active matrix liquid crystal display device can be manufactured using the substrate according to a known method.

[0064]

The excimer laser is used as the laser oscillator in the above example. The excimer laser is appropriate for the optical system in the above example because it has a very short coherent length as short as several μm. Some of the lasers shown below have a long coherent length. In the case of using such a laser, when the divided beams are combined in such a way that they have optical-path difference one another before being combined, it is possible to suppress the generation of the interference. Alternatively, the coherent length may be changed intentionally by making the laser transmitted through an optical fiber or the like before the laser is incident on the optical system, and then the laser may be introduced into the homogenizer. It is also preferable to employ a harmonic of the YAG laser or a harmonic of the glass laser because they can output high energy similarly and the energy of the laser beam is absorbed sufficiently by the silicon film. There are a YVO_4 laser (harmonic), a YLF laser (harmonic), an Ar laser, and the like given as the other appropriate laser oscillator for crystallizing the silicon film. These laser beams have a range of wavelengths absorbed sufficiently by the silicon film.

[0065]

Although the above example uses the amorphous silicon film as the non-single crystal semiconductor film, it is easily supposed that the present invention can be applied to the other non-single crystal semiconductor. For example, a compound semiconductor film having an amorphous structure such as an amorphous silicon germanium film may be used as the non-single crystal semiconductor film. A poly-crystalline silicon film may be used as the non-single crystal semiconductor film

alternatively.

[Embodiment 1]

[0066]

Fig. 3 shows an example of an optical system including an optical waveguide to be explained in this embodiment. A light pipe can be used as the optical waveguide. First, a plane view of Fig. 3(a) is explained. A laser beam emitted from a laser oscillator 301 is propagated to the direction indicated by an arrow in Fig. 3. In the plane view of Fig. 3(a), the vertical direction on the paper is the direction of the minor axis of the rectangular beam spot.

[0067]

Initially, the laser beam is expanded by spherical lenses 302a and 302b. When the laser oscillator 301 emits a sufficiently large beam spot, such a structure is not necessary. It is noted that the optical system for expanding the shape of the beam spot such as the spherical lenses 302a and 302b is generally referred to as a beam expander.

[0068]

The laser beam expanded through the beam expander is focused in the direction of the major axis of the rectangular beam spot through a cylindrical lens 303 having a thickness of 20 mm with the first surface having a radius of curvature of 194.25 mm and the second surface being plane. The sign of the radius of curvature is positive when the center of the curvature is on the light beam exit side with respect to the lens surface. The sign is negative when the center of the curvature is on the light beam incident side with respect to the lens surface. In addition, it is noted that a lens surface where the laser beam is incident is defined as the first surface, and a lens surface where the laser beam exits is defined as the second surface.

[0069]

An optical waveguide 304 including a pair of reflection planes 304a and 304b provided oppositely is arranged in such a way that the entrance of the optical waveguide 304 is positioned at the focal point of the cylindrical lens 303. The laser beam being incident on the optical waveguide 304 is reflected repeatedly in the optical waveguide 304 so as to homogenize the energy distribution thereof and then the laser beam is led to the exit. A plane having the homogeneous energy distribution in the direction of the major axis of the rectangular beam spot is formed at the exit of the optical waveguide

304. The optical waveguide 304 has a length of 200 mm in the direction to which the laser beam travels, and a distance of 2 mm between the reflection planes.

[0070]

A cylindrical lens 305 has a thickness of 5 mm with the first surface having a radius of curvature of 9.7 mm and the second surface being plane, which is positioned 20 mm behind the exit of the optical waveguide 304. A plane having the homogeneous energy distribution in the direction of the major axis of the rectangular beam spot formed at the exit of the optical waveguide 304 is projected by the cylindrical lens 305 on an irradiation surface 309, which is positioned 3600 mm behind the cylindrical lens 305. In other words, the plane having the homogeneous energy distribution in the direction of the major axis and the irradiation surface 309 are conjugated with respect to the cylindrical lens 305. This homogenizes the energy distribution of the rectangular beam spot in the direction of its major axis and determines the length thereof in the direction of its major axis. In this embodiment, the cylindrical lens 305 is employed as the lens for projecting the laser beam emitted from the optical waveguide 304 on the irradiation surface 309. In order to reduce aberration more, however, a doublet cylindrical lens is also applicable. The doublet cylindrical lens is a set of lenses consisting of two cylindrical lenses. A set of lenses consisting of three or more lenses may be also used alternatively. The number of lenses may be determined in accordance with the designed system or required specification.

[0071]

Next, a side view of Fig. 3(b) is explained. The laser beam emitted from the laser oscillator 301 is expanded through the beam expander including the spherical lenses 302a and 302b. The laser beam expanded through the beam expander is focused in the direction of the minor axis of the rectangular beam spot through a cylindrical lens 306 having a thickness of 20 mm with the first surface having a radius of curvature of 486 mm and the second surface being plane, which is positioned 773.2 mm behind the cylindrical lens 305.

[0072]

An optical waveguide 307 having a pair of reflection planes 307a and 307b provided oppositely is arranged in such a way that the entrance of the optical waveguide

307 is positioned at the focal point of the cylindrical lens 306. The laser beam being incident on the optical waveguide 307 is reflected repeatedly in the optical waveguide 307 so as to homogenize the energy distribution thereof and then the laser beam is led to the exit. A plane having the homogeneous energy distribution in the direction of the minor axis of the rectangular beam spot is formed at the exit of the optical waveguide 307. The optical waveguide 307 has a length of 250 mm in the direction to which the laser beam travels, and a distance of 2 mm between the reflection planes.

[0073]

A doublet cylindrical lens 308a and 308b arranged in the position 1250 mm behind the exit of the optical waveguide 307 projects the plane having the homogeneous energy distribution in the direction of the minor axis of the rectangular beam spot formed at the exit of the optical waveguide 304 on the irradiation surface 309 positioned 237 mm behind the doublet cylindrical lens.

[0074]

One of two cylindrical lenses constituting the doublet cylindrical lens has the first surface having a radius of curvature of 125 mm and the second surface having a radius of curvature of 77 mm, and has a thickness of 10 mm. The other cylindrical lens has the first surface having a radius of curvature of 97 mm and the second surface having a radius of curvature of -200 mm and has a thickness of 20 mm. The two cylindrical lenses are arranged to have a distance of 5.5 mm in between. This homogenizes the energy distribution of the rectangular beam spot in the direction of its minor axis and determines the length thereof in the direction of its minor axis. The irradiation surface may be arranged just after the optical waveguide 307 without employing the doublet cylindrical lens, but when the doublet cylindrical lens is employed, a spatial margin can be given because a distance can be secured between the optical system and the irradiation surface.

[0075]

The optical system including the optical waveguide shown in Fig. 3 can form a rectangular beam spot having a length of 300 mm in its major axis, and a length of 0.4 mm in its minor axis and having the homogeneous energy distribution. Fig. 4 shows the simulation result by optical design software. Fig. 4(a) is a chart to show the energy distribution of the beam spot formed on the plane having a size of ±200 mm in the

direction of the major axis and ±0.3 mm in the direction of the minor axis from the center of the rectangular beam spot. Figs. 4(b) and 4(c) are cross-sectional views of the energy distribution taken along a line A and a line B shown in Fig. 4(a) respectively. A vertical axis shows the laser intensity (A.U.), and a horizontal axis shows the length (mm).

[0076]

The laser annealing is performed to the semiconductor film with the optical system including the optical waveguide shown in this embodiment with the method according to the embodiment mode, for example. The semiconductor film can be used to manufacture an active matrix liquid crystal display device for example. A practitioner may manufacture this device according to a known method.

[Embodiment 2]

[0077]

This embodiment shows an example of the different optical system from the one described in the embodiment mode. Fig. 5 shows an example of the optical system to be explained in this embodiment. It is noted that a light pipe can be used as the optical waveguide.

[0078]

The laser beam in Fig. 5 goes through totally the same optical path as that shown in Fig. 3 except when the laser beam goes through the optical waveguides 504 and 507. Each of the optical waveguides 504 and 507 has a pair of reflection planes provided oppositely as well as the optical waveguide 304. The optical waveguide 304 has a hollow space between the pair of reflection planes provided oppositely. On the other hand, each of the optical waveguides 504 and 507 has the space between the pair of reflection planes filled with the medium having a refractive index of n (>1). This is the different point between these optical waveguides. When the light beams are incident on the optical waveguides 504 and 507 at a critical angle or more, the light beams are all reflected on the reflection plane according to the same principle as the optical fiber. For example, when the optical waveguide made of quartz (refractive index is approximately 1.5) is arranged in the air, it is possible to obtain the optical waveguide having total reflection planes in the interface between the optical waveguide and the air. In the case that the optical waveguide as above is employed, the

transmittance of the laser beam becomes considerably high compared to the case when the laser beam is not totally reflected. Thus, the laser beam emitted from the laser oscillator 501 can be propagated to the irradiation surface 509 more effectively.

[0079]

It is noted that an optical waveguide of a multilayer structure may be used instead of the optical waveguides 504 and 507 in Fig. 5. Typically, an optical waveguide, which is made of two materials as shown in Fig. 7(A), and whose refractive index of an inner material 702 (quartz including germanium, for example) is higher than that of an outer material 701 (quartz, for example), can be used.

[0080]

Fig. 7(B) is a cross-sectional view taken along a line (A)-(A') in the optical waveguide shown in Fig. 7(A). In addition, Fig. 7(C) is an enlarged view of the reflection plane in Fig. 7(B). When light beams 703 are incident on the optical waveguide at an incidence angle θ not less than the critical angle θ_0, the incident light beams are totally reflected between the pair of reflection planes provided oppositely.

[0081]

It is noted that a coating for reducing a reflectivity may be formed on the entrance surfaces of the optical waveguides 504 and 507 timely in order to reduce the reflectivity of the laser beams at the entrance surfaces of the optical waveguides when the laser beam is incident on the optical waveguides 504 and 507.

[0082]

The optical system shown in Fig. 5 can form a rectangular beam spot having a size of 300 mm in the direction of its major axis and 0.4 mm in the direction of its minor axis and having the homogeneous energy distribution.

[0083]

The laser annealing is performed to the semiconductor film using the optical system shown in this embodiment with the method according to the invention embodiment mode, for example. The semiconductor film can be used to manufacture an active matrix liquid crystal display device or a light-emitting device for example. A practitioner may manufacture the devices according to a known method.

[Brief Description of the Drawings]

[0084]

[Fig. 1] A drawing to explain homogenization of the energy distribution of the beam spot by an optical waveguide.

[Fig. 2] A drawing to show an example of a beam homogenizer with the use of an optical waveguide disclosed in the present invention.

[Fig. 3] A drawing to show an example of a beam homogenizer with the use of an optical waveguide disclosed in the present invention.

[Fig. 4] The energy distribution of the rectangular beam spot obtained by the beam homogenizer shown in Fig. 3.

[Fig. 5] A drawing to show an example of a beam homogenizer with the use of an optical waveguide disclosed in the present invention.

[Fig. 6] A drawing to show a conventional beam homogenizer.

[Fig. 7] A drawing to show an example of an optical waveguide disclosed in the present invention.

[Name of Document] Abstract

[Abstract]

[Problem]

The present invention provides a beam homogenizer being able to form a rectangular beam spot having homogeneous energy distribution in a direction of its major axis on an irradiation surface without using the optical lens requiring to be manufactured with high accuracy. In addition, the present invention provides a laser irradiation apparatus being able to perform irradiation with the laser light having a rectangular beam spot whose energy distribution is homogeneous in a direction of its major axis. Furthermore, the present invention provides a method for manufacturing a semiconductor device being able to enhance the homogeneity of the crystallinity in a substrate surface and to manufacture TFT with a high operating characteristic.

[Solving Means]

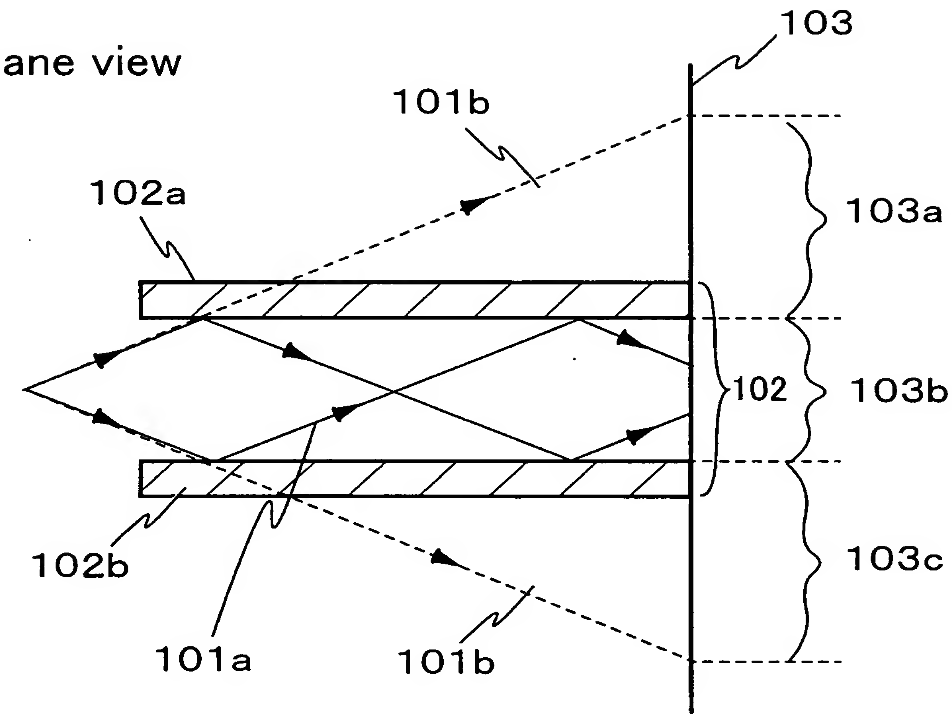
The beam homogenizer, one of the present invention, has a feature to shape the beam spot on the irradiation surface into a rectangular spot having an aspect ratio of 10 or more, preferably 100 or more, and to include an optical waveguide for homogenizing the energy distribution of the rectangular beam spot in the direction of its major axis.

[Selected Drawing] Fig. 2

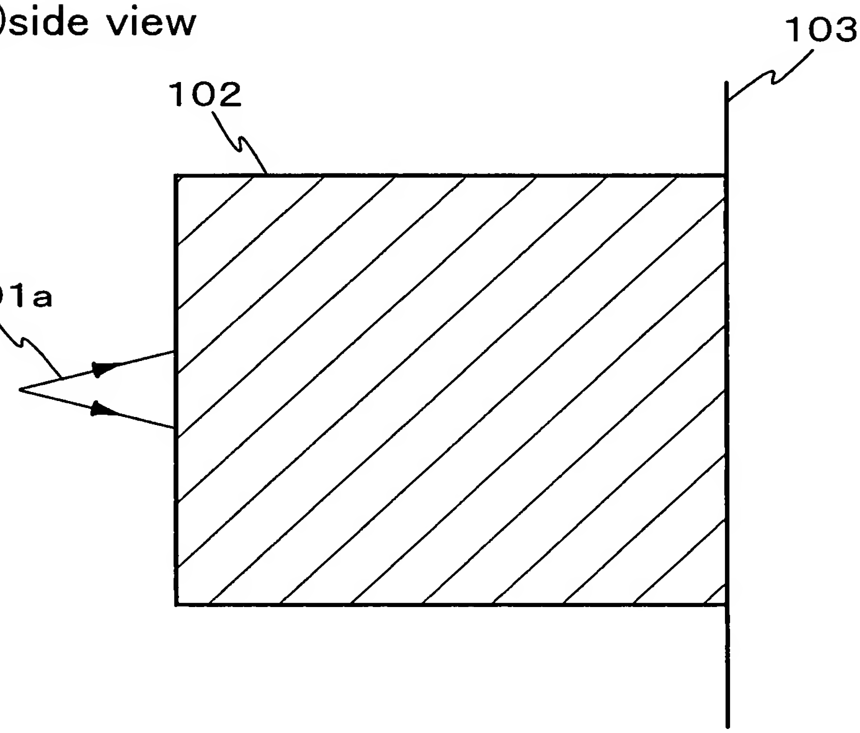
[Name of Document] Drawing

【Fig.1】

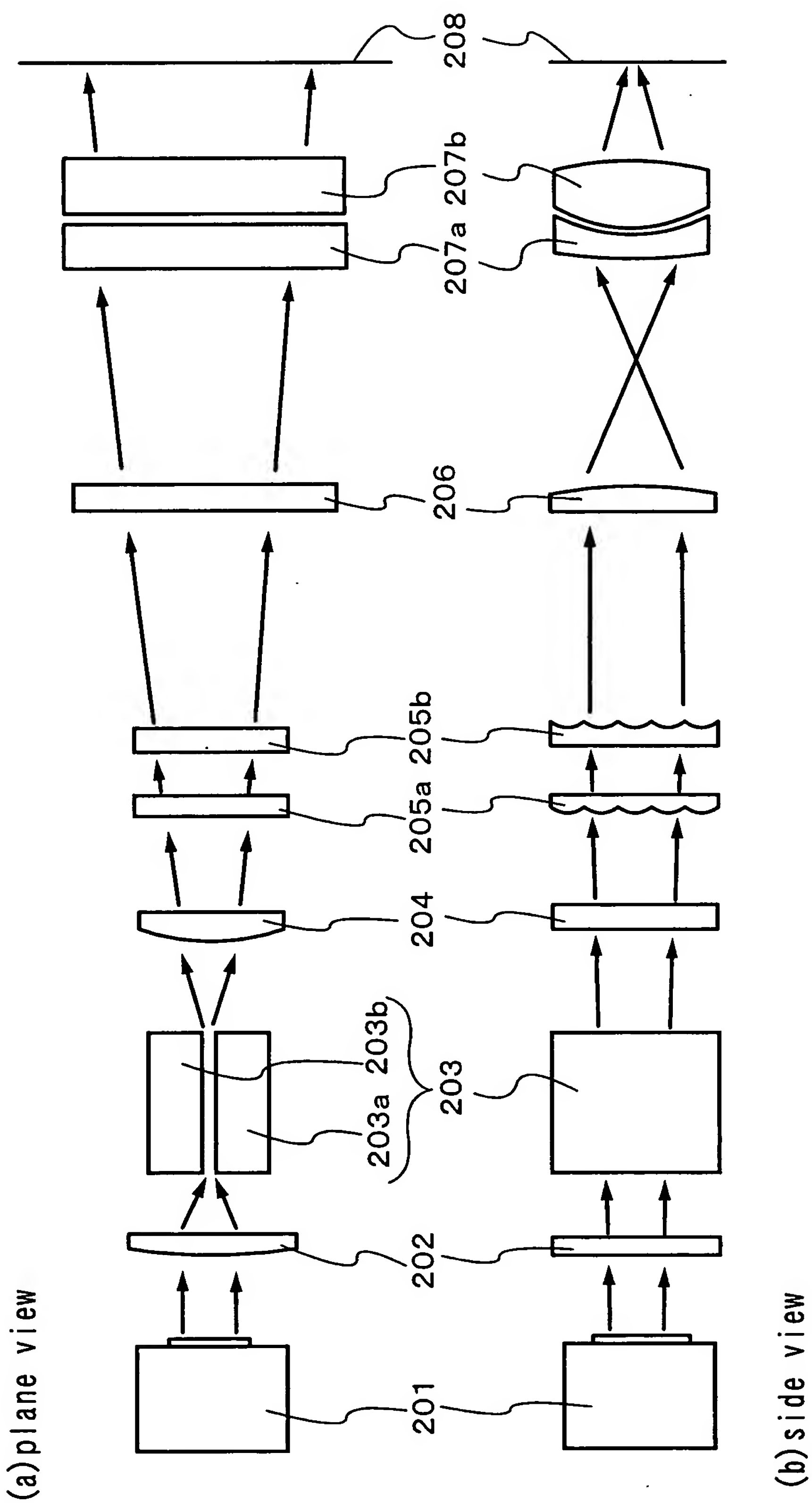
(a)plane view



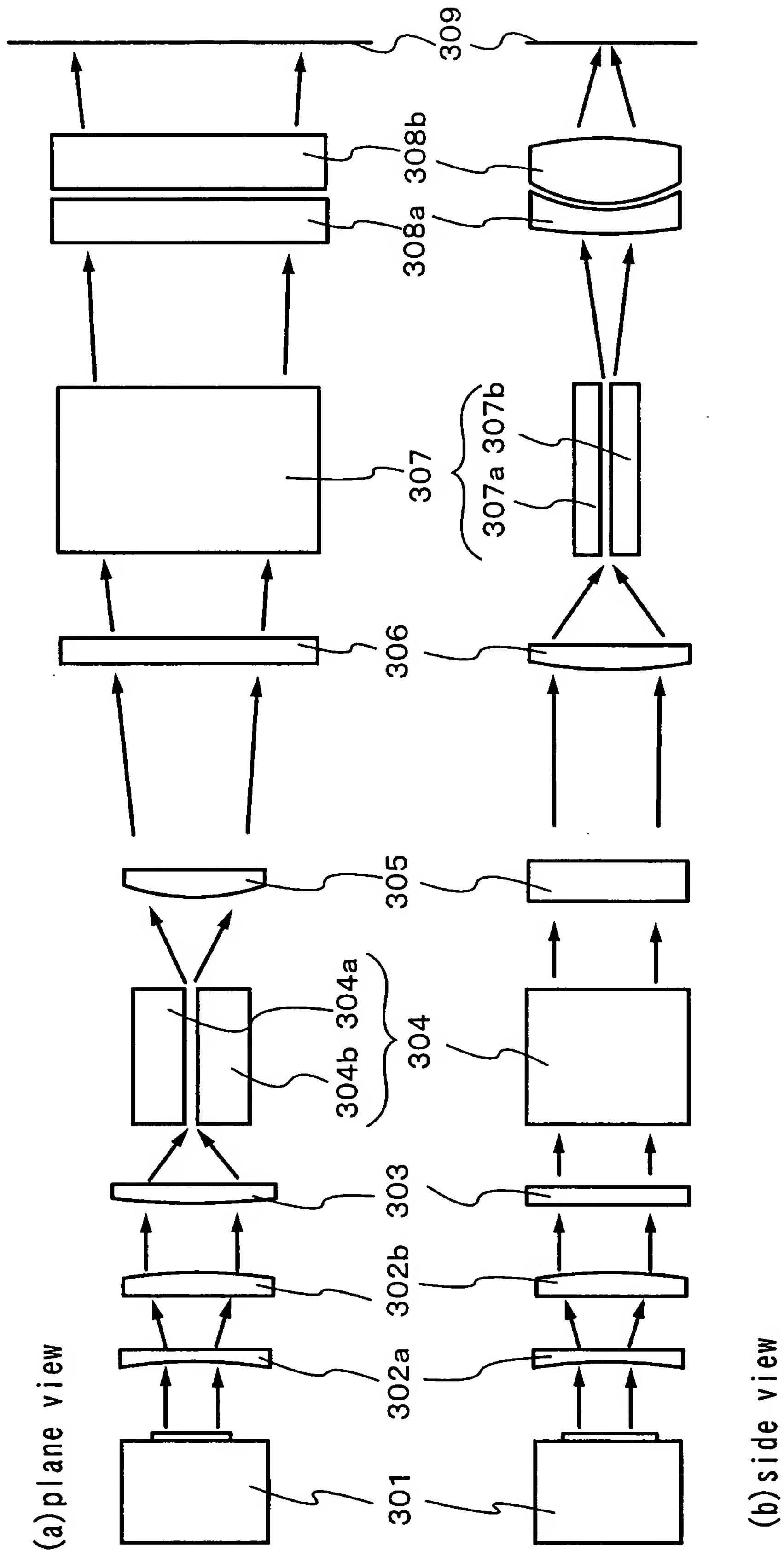
(b)side view



【Fig.2】


(a)plane view
(b)side view
201
202
203
203a
203b
204
205a
205b
206
207a
207b
208

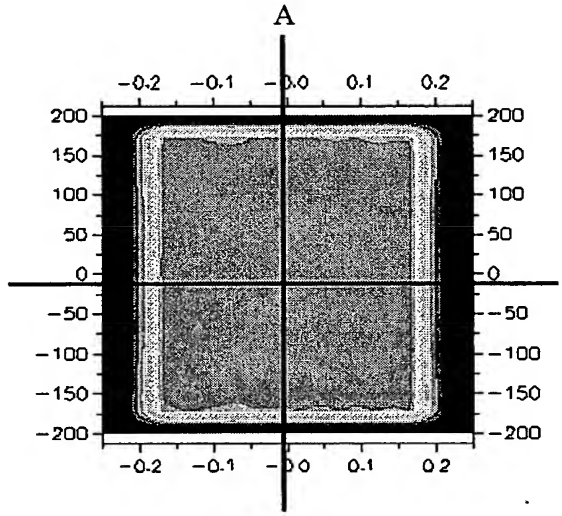
【Fig.3】



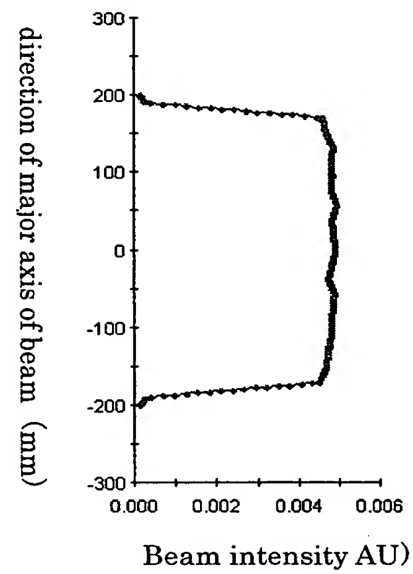
(a)plane view
(b)side view
301
302a
302b
303
304
304a
304b
305
306
307
307a
307b
308a
308b
309

【Fig. 4】

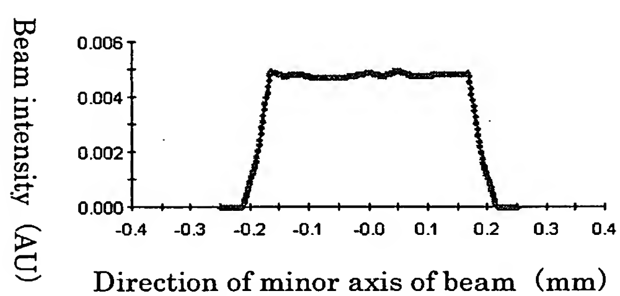
(a)



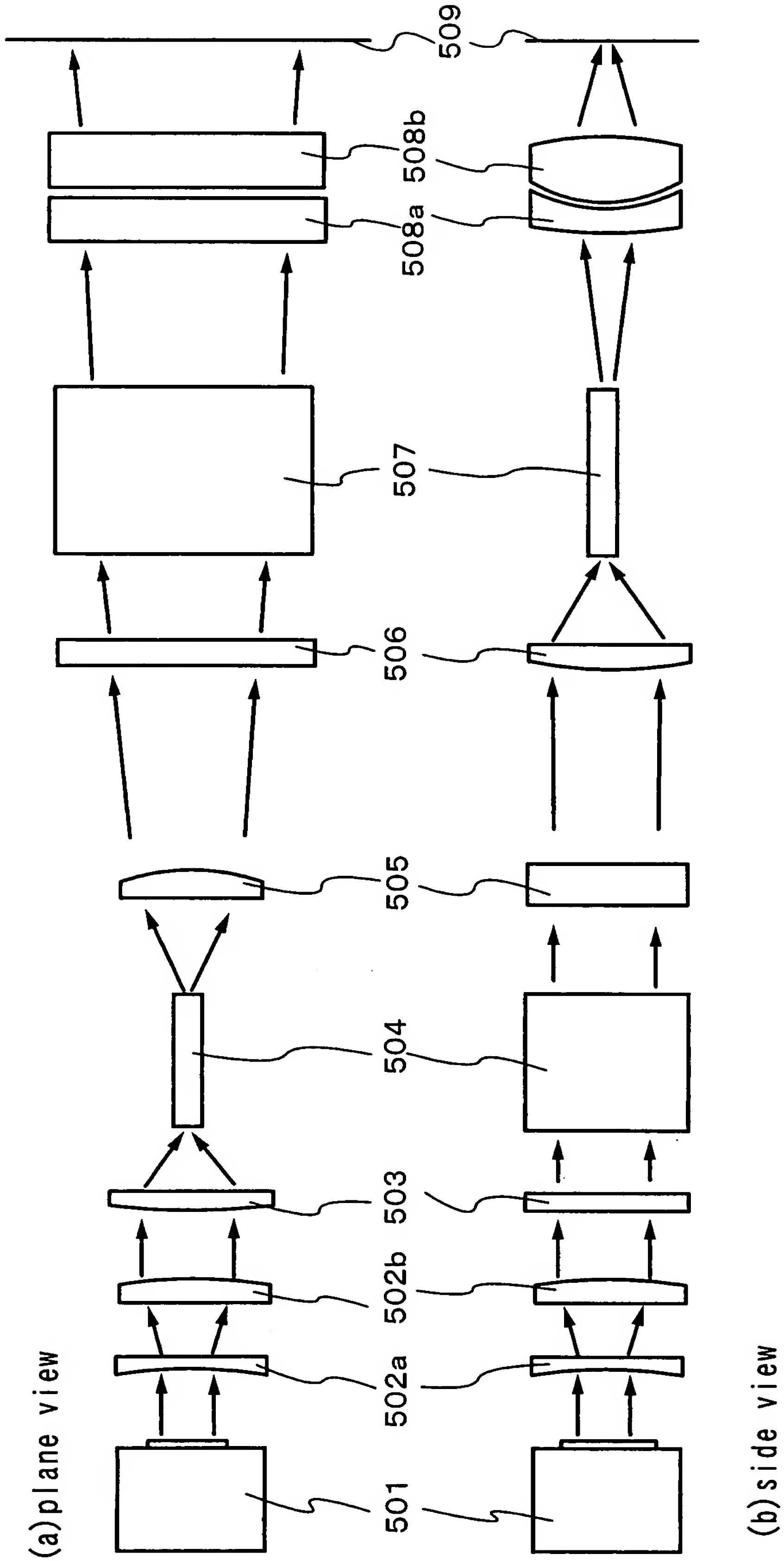
(b) side view of A



(c) side view of B



【Fig.5】

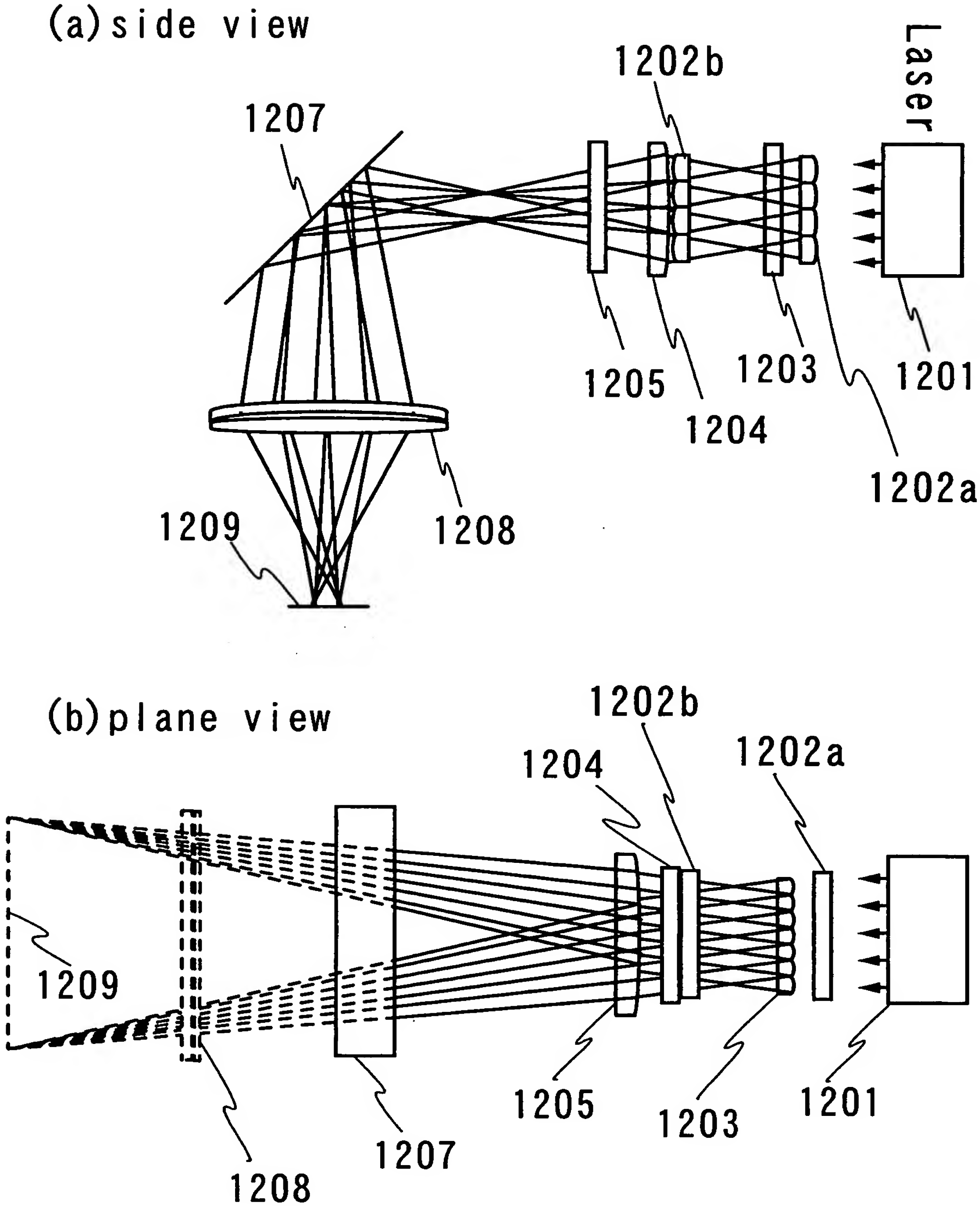


(a) plane view
(b) side view
501
502a
502b
503
504
505
506
507
508a
508b
509

【Fig. 6】

(a) side view

(b) plane view



【Fig.7】